Date: December 28, 2018

EIC Detector R&D Progress Report

Project ID: eRD16
Project Name: Forward/Backward Tracking at EIC using MAPS Detectors
Period Reported: from July 2018 to December 2018
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Abstract

This report describes progress in the period between July and December 2018 on continued conceptual development of tracking stations with silicon-sensors near the collision vertex to detect the scattered electron and produced secondary hadrons at forward and backward angles with respect to the beams at a future Electron-Ion Collider. The focus is on disks with thinned-silicon sensors with the overall goal to arrive at science-driven sensor specifications, optimized geometrical configuration of the forward/backward disks, disk layout, conceptual arrangement of services, and integration with tracking subsystems covering the central barrel region. Part of this work is being pursued in collaboration with eRD18, which focuses on sensor development and mid-rapidity (vertex) tracking.

Introduction

The 2015 Long Range Plan for Nuclear Physics [1] recommends the construction of an Electron-Ion Collider (EIC) facility to study the role(s) of gluons in nucleons and nuclei, a science case that has now been independently assessed and strongly endorsed in a consensus study report by the National Academies of Sciences, Engineering, and Medicine [2]. The EIC facility is envisioned to be built as an upgrade to the Relativistic Heavy Ion Collider accelerator at Brookhaven National Laboratory or as an upgrade to the Continuous Electron Beam Accelerator Facility at Thomas Jefferson National Accelerator Laboratory. The EIC is scheduled to come online in the 2030 timeframe. Generic EIC research and development is required to ultimately construct optimized detectors to observe and gain insight into the science.

The ultimate multi-year goal of eRD16 is to develop an optimized conceptual design for well-integrated, precision endcap trackers that are part of a main collider detector at the EIC utilizing monolithic active pixel sensors (MAPS). Achieving this goal requires research and development in several areas. The eRD16 and eRD18 groups are collaborating to carry out this work.

Unobserved losses of the scattered electron's energy, e.g. bremsstrahlung, introduce a bias in Bjorken-*x,* typically towards smaller values. Traversed material thus needs to be kept to a minimum. The hemisphere along the direction of the EIC ion beam is of considerable scientific interest as well. Here, new insights are anticipated for example from the production of heavy quarks and jets, and their propagation through cold nuclear matter. Particle energies along the direction of the forward-going hadron beam are typically considerably higher than those along the forward-going electron beam at an EIC. In general, tracking imposes considerable challenges in the 1.5 and 3T solenoidal fields that are under consideration for the general purpose EIC detector concepts. Successful EIC endcap trackers must provide excellent momentum resolution over wide ranges that are different for the electron and ion beam regions. They must have low mass. Together with the barrel tracker, they must provide full azimuthal and (near) full polar coverage. These and other aspects point to a need to develop low-mass, well-integrated, barrel and endcap silicon trackers.

Accomplishing this goal is multi-year activity, which LBNL and Birmingham have proposed to undertake together. LBNL has engaged in simulation studies to aid the specification of dedicated sensors and optimized barrel and endcap conceptual design. LBNL and Birmingham collaborate in a number of these physics simulations and simulations to arrive at a sensor design. Once fully specified, the new sensors need to be laid out and simulated to demonstrate the feasibility of sensor design and their production. Prototype sensors will subsequently need to be produced and tested. Furthermore, the readout speed, heat load and cooling, along with mechanical concept for barrel and endcaps will need to be worked out. Birmingham will pursue prototype sensor production, and produced sensors can be tested at both Birmingham and LBNL.

In the sections below, we describe recent progress related to these areas for the proposed forward tracking stations. This is followed by planned effort for the remainder of this proposal period.

Past

The development of the envisioned low-mass MAPS-based endcap trackers requires advances in multiple areas, including overall layout, mechanical support and integration, cooling, and low-mass conductor cables. The endcap and barrel silicon trackers, as well as their services, require coordination of their designs. Among other, their infrastructure must not interfere with one another and must be compatible with the full range of main EIC science objectives. This presents challenges, for example for the integration of the innermost barrel layers and the discs nearest to the nominal collision point.

eRD16 pursues these and other simulations with two independent toolsets. We make use of EICroot, developed at BNL specifically for GEANT-based EIC detector simulation and used in particular for the BeAST general-purpose detector concept [3]. Separately, we use a fast-simulation toolset that was developed originally for tracking studies for the ILC detector concepts [4]. This toolset performs a simplified simulation of the detector measurements, based on a helix track model and taking into account multiple scattering, followed by full single-track reconstruction from digitized hits using a Kalman filter.

Figures 1 and 2 contain examples of recent results in the form of (1) a momentum scan of the anticipated relative momentum resolution for charged particles produced at a pseudo-rapidity of $\eta = 3$ for an equidistant set of five and seven disks positioned orthogonal to the beamline at positions between $z = 0.25$m and $z = 1.21$m from the nominal interaction point and (2) the (same) five-disk scan for a range of pixel sizes. Both are for a 3T solenoidal field. Unlike previously reported scans, which were based on fast simulations [4], these simulations were performed in EICroot.

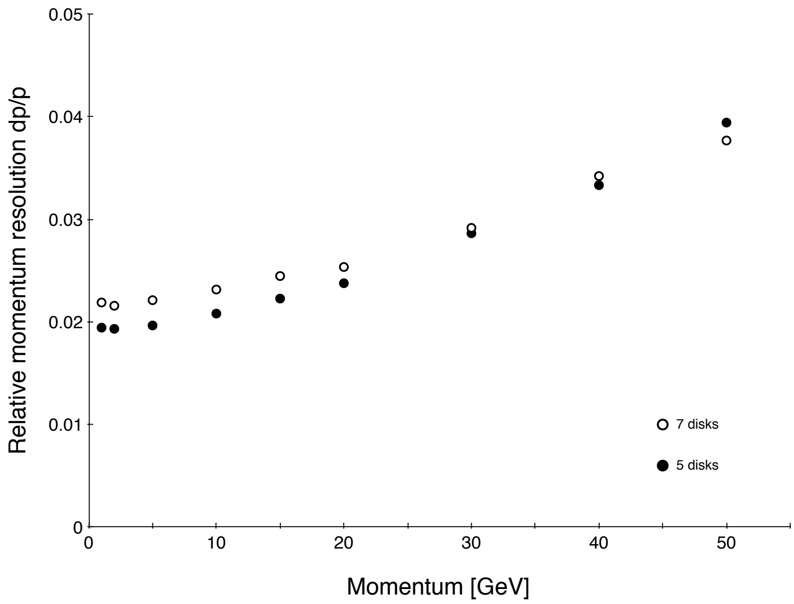

Figure 1: The relative momentum resolution as a function of absolute momentum for standalone tracking with 5 and 7 equidistant disks (as indicated) spanning $z = 0.25m$

to z=1.21m in a 3T solenoidal field along z. The sensor's pixel size is 20×20 microns in these simulations and the thickness of each disk is χ_0 = 0.3%. The statistical uncertainties are comparable in size to the symbol size.

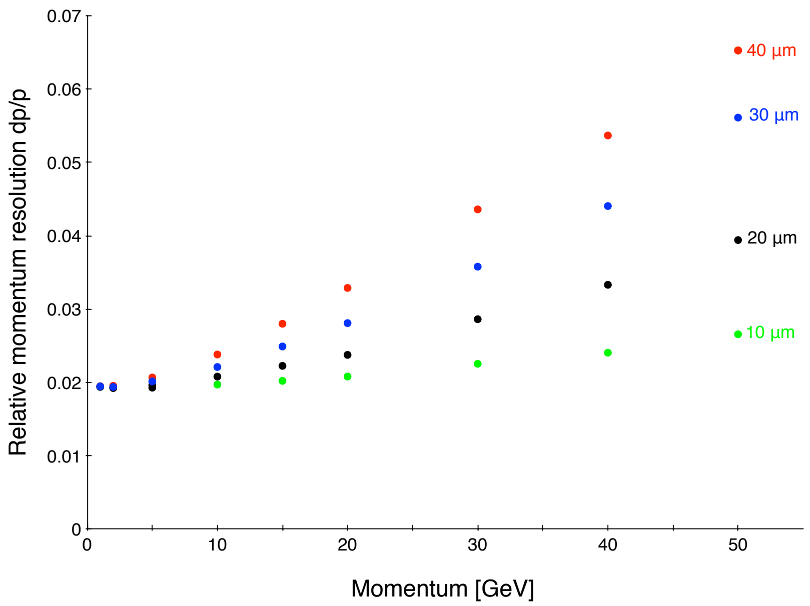

Figure 2: The simulated relative momentum resolution as a function of absolute momentum for standalone tracking with 5 for different pixel sizes (as indicated). The magnetic field and thickness of each disk, as well as their configuration, is the same as for Figure 1.

These results lead to similar conclusions as those previously obtained from the corresponding fast-simulations; ~20 μm square pixels will suffice for momentum and position measurement at an EIC for the detector configurations being considered as well as the stringent requirement to minimize mass, especially in the direction along the forward electron beam momentum (negative scattering angles, in the HERA convention). We have studied and are continuing to study the qualitative and quantitative (dis-)similarities of these and other results to similar results previously obtained with the fast simulation toolset. In particular, we note that the values here are fits to the central distributions in a 2-3 sigma window so as to avoid distribution tails from causes that are not part of in the fast simulations.

Figure 3 shows a momentum scan for seven-disk configurations from the fast simulation toolset. The open dots can indeed be compared to those in Figure 1. The qualitatively different degradation of the resolution at the smallest momentum values in the fast simulations has its origin in multiple scattering through the beam-pipe to obtain the momentum at the beam-collision vertex. EICroot simulations give identical results for (reasonable) variations in the beam-pipe thickness, consistent with a measurement at or near the location of the disks.

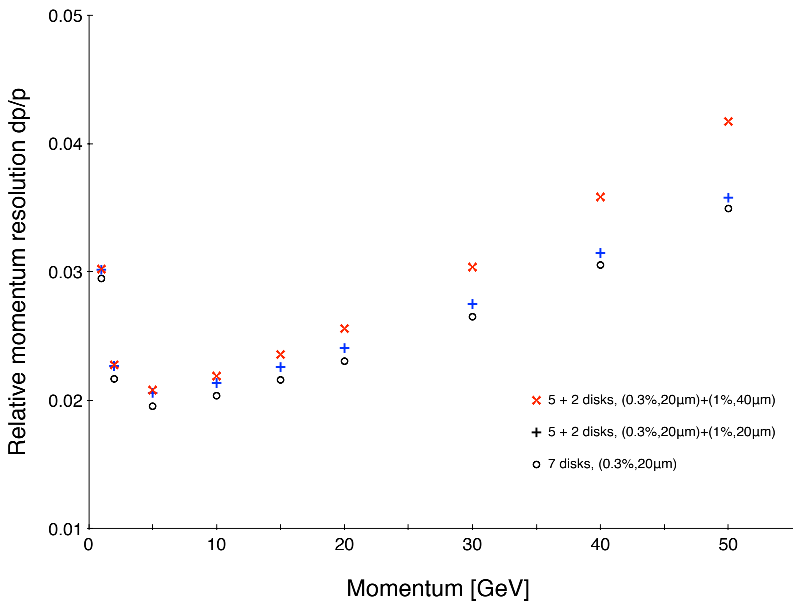

Figure 3: The estimated relative momentum resolution from fast simulations as a function of absolute momentum for standalone tracking with several 7 disk configurations described in the text. The magnetic field and the configuration of the disks is the same as for Figures 1 and 2.

The results for alternative disk configurations in Figure 3, shown as crosses, are for equidistant configurations where the two disks furthest from the interaction region have a higher radiation thickness and in one case also a larger pixel size (as indicated). This simulation was initially motivated by a (hypothetical example of a) fast timing layer as suggested in various contexts by eRD6, eRD18, and us. Such a layer could serve to reduce track-pileup, which was noted by the committee and estimated in our previous work to be a modest need for the anticipated luminosities and track multiplicities at an EIC. It could serve also to "anchor" a slower detector to the beam crossing and, hence, the beam-spin configuration. Ref. [5] suggests that, with considerable further technological development, such a layer might even serve Time-of-Flight purposes. The results in Figure 3 indicate only a modest degradation of the standalone momentum resolution from a radiation thickness of the outermost disks beyond the nominal $\chi_0 = 0.3\%$ (irrespective if such an increase were to come about from the integration of a, presumably thicker, timing layer as part of this tracking subsystem or from other considerations).

Figure 4 shows a barrel and endcap configuration (left) and its estimated momentum resolution from fast-simulation (right). In this configuration, the radii of the six disks increase linearly with z while z is within the (half-)length of the outermost barrel layer(s) and then remains constant. The length of the intermediate barrel layer(s) is adjusted accordingly, while the length of the innermost barrel layer(s) is driven primarily by vertexing needs. Mechanical support and services could, at least initially, be at constant pseudo-rapidity in such a configuration. The intermediate and outer barrel layers shown here correspond to the configuration of the ALICE-ITS [6], whereas the two innermost barrel layers follow one of the configurations considered by eRD18.

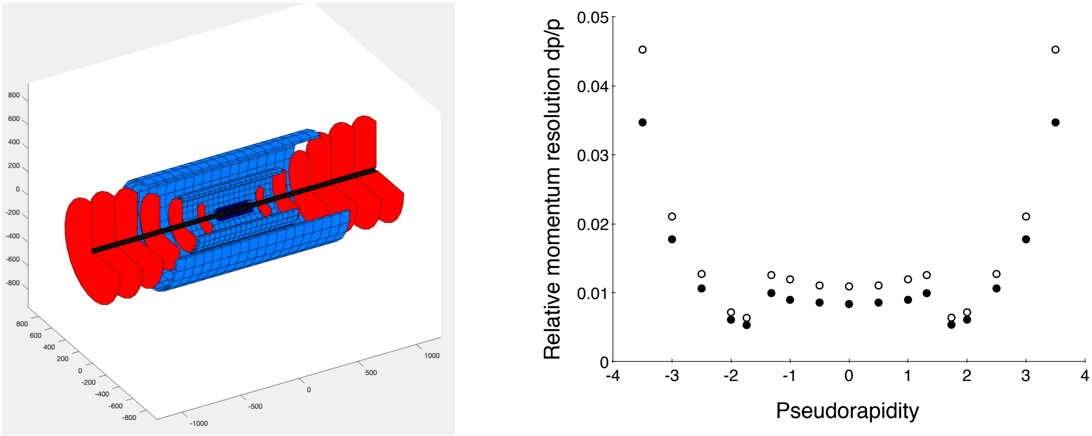

Figure 4: (left) Schematic view of an all-silicon barrel and endcap tracking configuration. The combined spatial extent is |z| < 1.21m and r < 0.43m. The radiation thickness of the innermost barrel layers and the disks is χ_0 = 0.3%, whereas the intermediate and outer barrel layers have a is χ_0 = 1%. Other aspects of the configuration are discussed in the text. (Right) Relative momentum resolution versus pseudorapidity for standalone tracking of 5 GeV (filled circles) and 20 GeV (open circles) charged particles from fast-simulation.

The steps near $|\eta| = 1.5$ in Figure 4 (right) have their origin in the trade-off between the length of the inner-most barrel layers, driven by vertexing needs, and the positioning of the inner-most disks. Several other such configurations have been and are being simulated; we intend to summarize these at the meeting in January and will document them in a write-up on fast-simulations.

Future

In the remaining 6 months of the ongoing proposal period, we will:

- Document our fast-simulations to date,
- Incorporate one or more promising detector configurations in full-simulations, evaluate their performance, and compare with baseline simulations,
- Investigate with physics simulation if concentrating support and services along a cone (c.f. Figure 4) indeed offers physics advantages compared to configurations that would distribute such more evenly,
- Start investigating (im-)practicalities of integration with a mechanical engineer once the above investigations are somewhat further along and the trade-offs are better understood.

This work will be pursued together with eRD18. We will also continue to extend our simulations towards an all-silicon concept.

For the upcoming proposal period we intend to (re-)integrate hardware efforts aimed at low-mass conductors, cooling, and possibly aspects of sensor development.

Staffing

In this reporting period, forward disk conceptual design simulation efforts have been carried out by Project Scientist Yue Shi Lai, ES, and several younger scientists. Lai's EIC effort is supported by eRD16 funds and concerns simulations within the BNL-developed EICroot framework. He is completing already started EICroot studies. A new UC-Berkeley graduate student, Ezra Lesser, familiarized himself with aspects of this framework over Summer. Stony Brook University undergraduate Emily Biermann was part of the group at LBNL during Summer. She was engaged in the fast-simulation efforts.

External Funding

As noted in earlier reports, several of the eRD16 co-authors were part of an LBNL strategic LDRD that has enabled efforts distinct from, but with synergies with, the effort discussed here. This LDRD has ended per October 2018.

As noted in the past report, several of us and colleagues from other University of California (UC) campuses prepared and submitted a full proposal in response to a 2019 UC Multi-campus Research Funding Opportunity. This proposal has just been awarded and should make it possible for us to engage part-time one or more UC graduate students in EIC-related Si-tracking efforts.

Publications

N/A for this reporting period.

References

[1] D. Geesaman et al., *Reaching for the Horizon: The 2015 Long Range Plan for Nuclear Science*.
[2] National Academies of Sciences, Engineering, and Medicine, *An Assessment of U.S.-Based Electron-Ion Collider Science*. https://doi.org/10.17226/25171 (2018).
[3] E.C. Aschenauer et al., arXiv:1409.1633 and references therein.
[4] M. Regler et al., J.Phys.Conf.Ser. 119 (2008) 032034 and references therein.
[5] Electron-Ion Collider Detector Requirements and R&D Handbook, Eds. A. Kiselev and T. Ullrich, v1.0 (2018).
[6] ALICE Collaboration, *Technical Design Report for the Upgrade of the ALICE Inner Tracking System,* CERN-LHCC-2013-024 ; ALICE-TDR-017 (2013).